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Enclosure 1

ARO W911NF-05-1-0163
FINAL TECHNICAL REPORT

Plantennas

Abstract

The Plantenna project has the overlying goal to simply use a plant as an antenna. To do this, special plants called metal hyper accumulators are being tested to observe any antenna like properties. The testing so far has been focused at finding an appropriate testing procedure while analyzing the basic impedance properties of plants concerning the relationships between impedance and test frequency and impedance and plant length. This report will illustrate that the plants behave in an expected manner with a linear relationship between the impedance and the plant distance as well as providing a valid testing procedure for use on the plants in question.

Introduction

The typical physiology of a plant dictates that metals found in the surrounding soil are harmful and therefore should not be accepted into the plant's body. Plants usually do not have to worry about increased levels of metallic ions in their environment. However, some places exist where the soil has had high metallic levels for a long period of time for example old mines in the Middle East. Naturally the surrounding plants were not immediately able to survive in this type of soil, but over time certain plants have evolved in order to live in this somewhat plant-hostile environment. These plants are able to absorb the metals and store them in their cell walls. These plants have been deemed metal hyper accumulators. Since metal hyper accumulators contain metals it is theoretically feasible that these plants can more efficiently conduct electricity than other types of plants.

Humans have become extremely adept at communicating with electromagnetic waves at various frequencies. Antennas of different designs and materials have been constructed during the last century to aid in the communication process. Before now, research has not been performed in the area of the possibility of using plants as an active antenna. The technology to genetically modify plants to make them better metal hyper accumulators and measure their performance as antennas now exists. The idea of using a plant as an antenna is a theoretical possibility, but several milestones must be overcome before this idea can evolve into a practically useful result.

The results that this report shows are meant to discover if a plant can have small enough impedance that will facilitate its use as an antenna. Typical antenna impedances are something on the order of 50 Ohms. The best method of obtaining impedance measurements from the plant must be determined. Part of this process is determining the equipment used and how to appropriately connect to the plant of interest. The initial testing deals with these aspects. Results of the efforts made to date in this specific area of research are included in this report.

Background

The Thlapsi is a naturally occurring metal-hyper accumulating plant. This specific plant must have metal in order to survive. The plants that are dealt with have been receiving treatments of Ni since they sprouted early in the fall of 2005. One specimen of the Thlapsi is shown in Figure 1. The plant in Figure 1 is a typical example of a Thlapsi with the flowering tall central stem and leafy bottom growth.

Since the goal of the project is to create the best antenna from a plant, a genetically modified plant will be created that will perform better than the naturally occurring Thlapsi. The Arabidopsis plant is a member of the mustard family whose genome has been entirely documented allowing genetic modifications to be made. The Thlapsi and the Arabidopsis share similar physical characteristics such as structure and size, thus making initial testing on the Thlapsi feasible.

Figure 1: Thlapsi

Methods

While the Thlapsi were growing to a size that permitted testing, some initial testing was performed on two different types of plants. This testing was done to try and refine the testing procedure. Grapevines and sunflowers were the two plants used in this phase of testing.

Initially the test setup consisted of a utilizing a voltage divider to measure the impedance of the plant. Figure 2 displays the basic test setup used with the voltage divider. A known current source was used that provided a constant voltage across the unknown resistance R_x which models the plant. The plants used in the voltage divider testing were cuttings from the original plant. The cuttings were inserted length wise into the circuit shown in Figure 2. Simple steel pins were used as connectors to the plant and electrically unshielded wiring was used to complete the circuit. Then the voltage across a variable resistance R_{pot} was measured until it was half of the voltage across R_x. The voltage measurements were made with an oscilloscope with a frequency generator providing the variable frequency current source. When the appropriate ratio had been determined, the R_{pot} was removed from the circuit and measured. This was the test setup used for both the grapevines and the sunflowers.

The grapevines cuttings were taken and used in the test setup described above. Cuttings taken directly from the plant were measured as well as other cuttings that had been loaded with metallic solutions of copper sulfate ($CuSO_4$). These plants were pressure loaded such that the metallic solutions were physically forced into the plant. Different concentrations of $CuSO_4$ were loaded into the grapevines for testing.

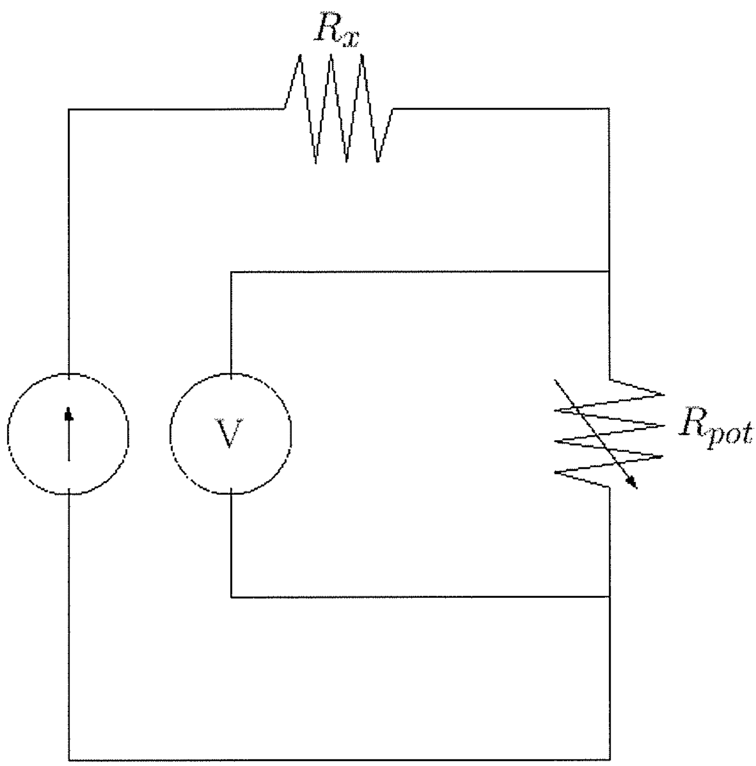

Figure 2: Voltage Divider

Sunflowers were also tested. Similar to the grapevine testing, a specific length of sunflower stalk was cut and then inserted into the test setup and tested at different frequencies. Testing a sunflower loaded with $CuSO_4$ was also desired, but proved infeasible. The sunflower stalks were too wide in diameter to safely pressure load. Another attempt to allow the plant to soak up the solution on its own was made by placing a sunflower whose stalk had been cut above the ground level into a container filled with the solution. This killed the sunflower and severely dried the plant out. There was also no good method of determining if there was a constant level of solution up the length of this plant that was allowed to naturally load.

While the testing on grapevines and sunflowers was underway, the Thlapsi were growing slowly. During this waiting period, analyzing the initial results and the test setup used led to improvements to the testing procedure. First of all, electrically shielded wires were incorporated into the testing apparatus. Secondly, the HP 4192A Impedance Analyzer was used to make more precise impedance measurements. Finally, the need to test live plants that will continue to grow became paramount due to the slow growth rate of the Thlapsi. Combining these three factors created the improved setup shown in Figure 3. Again simple pins were used to connect the testing apparatus to the plant.

The Impedance Analyzer is a self-contained four-wire impedance measurement device that utilizes its own variable frequency current source and voltmeter. Figure 4 contains a simplified diagram of the test setup. The resistors R_{I1}, R_{V1}, R_{V2} and R_{I2} represent the resistance of the probes. Connections to the plant are made at the two nodes above and below the unknown resistance R_X. This resistor, R_X, represents a length of plant of unknown impedance that is under test.

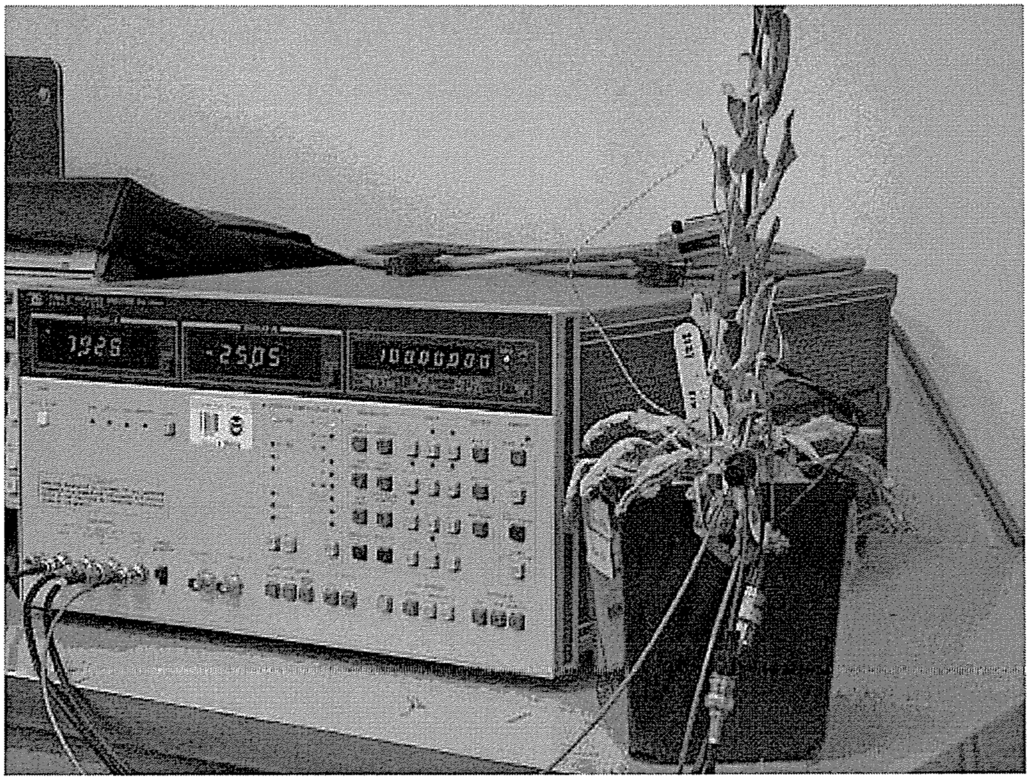

Figure 3: Refined Test Setup

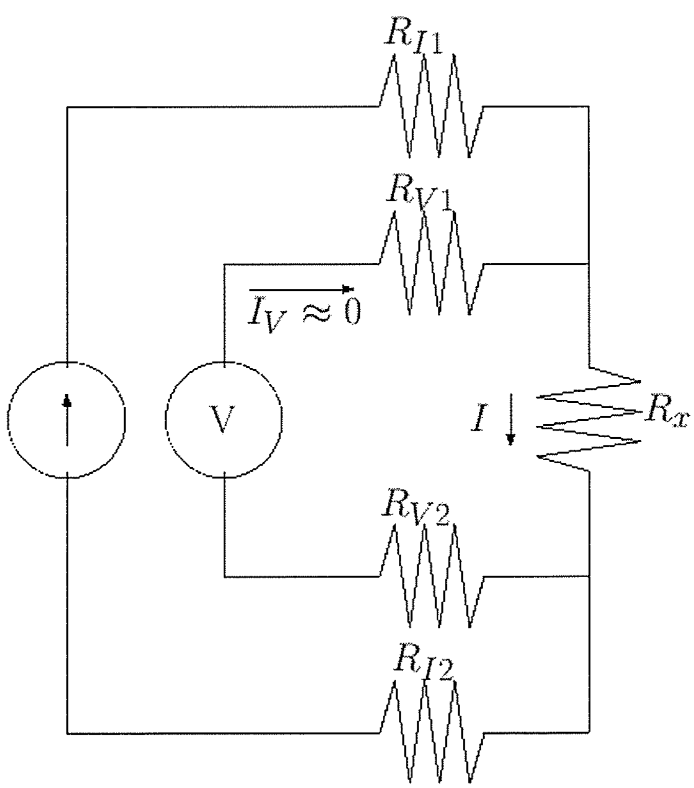

Figure 4: Four-wire Impedance Measurement

Results

The basic testing was first performed on an unloaded sunflower. The stalk was approximately 102.5 cm in length and 4 cm in diameter. As described above, the connections to the plant were made at the extremities where the plant had been cut. The results obtained by varying the frequency with a constant spacing are shown in Figure 5. The sunflower displays a logarithmic decline in impedance as the frequency increases. This trend is consistently observed with other plants.

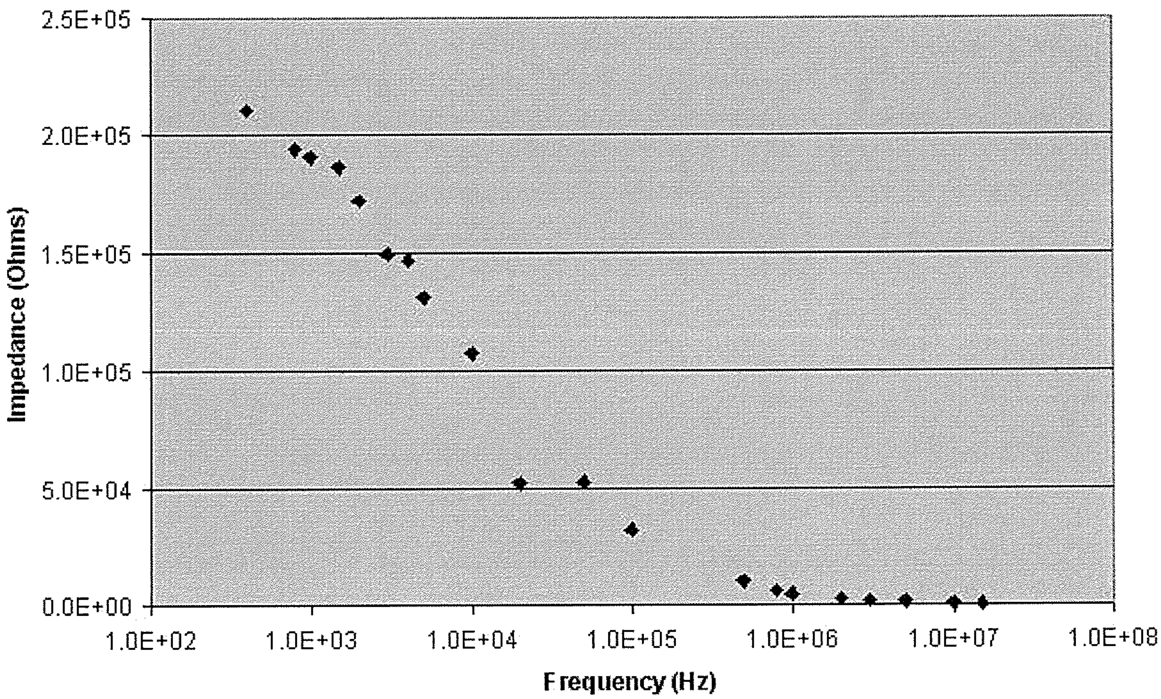

Figure 5: Sunflower Impedance

The various grapevines used in the same experiment that was performed on the sunflower displayed similar characteristics. Every grapevine tested except for the 2M $CuSO_4$ loaded vine was approximately 49 cm in length with diameters of 4 mm and 2 mm at the bottom and top respectively. The 2M loaded vine was shorter in length (only 33 cm) and was of a smaller diameter. It was expected that the impedance would drop with the addition of a conductive solution in the plant and these expectations are supported by the results in Figure 6. This was only valid for frequencies lower than 10 kHz. However, the 1 M vine had lower impedances than the 2 M plant for frequencies less than 10 kHz. It is felt that this can be attributed to two factors. The first is that the plant was of a smaller diameter. The second is that the 2 M plant was not tested quickly enough after loading with the $CuSO_4$ solution and gaps formed between pockets of the solution inside the plant due to a drying effect.

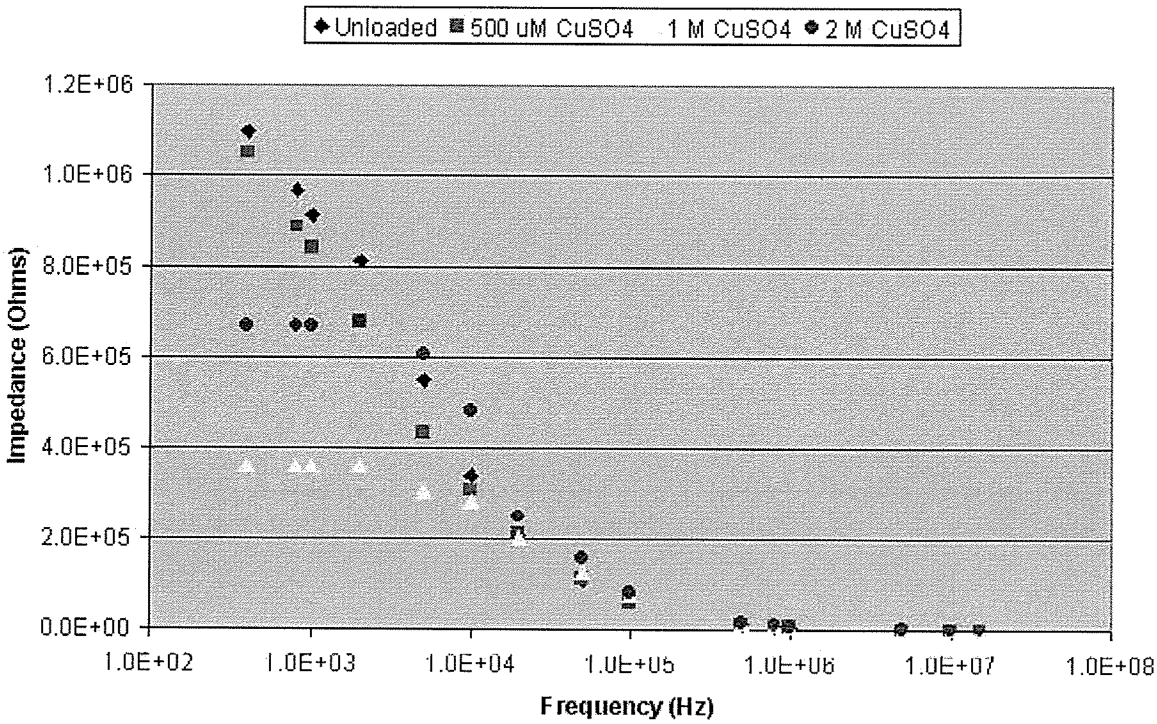

Figure 6: Grapevine Impedance

Questions about the validity of these initial tests arose and led to the modified testing procedure that was used for the more valuable Thlapsi plants. Three different types of Thlapsi were tested using the four-wire measurement. A four-digit number distinguishes the plants from one another. The 2121 and 2142 plants are both approximately the same diameter while the 2114 is smaller in diameter than the others. All impedance measurements are taken in Ohms. There is approximately 7.2 cm between probes for each test. For each plant there are two types of connections, platinum pins that were inserted into the plant 2 weeks prior to the experiment to allow the plant to grow around the pin and freshly inserted steel pins.

One part of the project was concerned with analyzing the effects of drying the plants out as compared to making measurements on uncut living plants. It can be seen from a comparison of Figures 7 and 8 that the impedances of the living plants were consistently one order of magnitude lower than those of the dried plants. This is because the liquid inside the plants aids in the conductance of the electrical current through the plant. Without the extra liquid, the impedance of the dried plants became extremely high even though the Thlapsi has been exposed to nickel, which should be stored in the plant's cellular walls.

It should also be noted that in Figure 7 the freshly inserted steel pins seemed to be able to make better contact, thus providing a lower impedance reading than the platinum pins provided. This is because the pins in the fresh connections were surrounded by more fluid in the plant. The platinum pins were placed in the plant to allow the plant to grow around the pin. This kept the plant from "bleeding" around the connection point and forcing extra fluids towards the pin. Again, the lack of the plant's fluid around the pins caused an increased in the impedance.

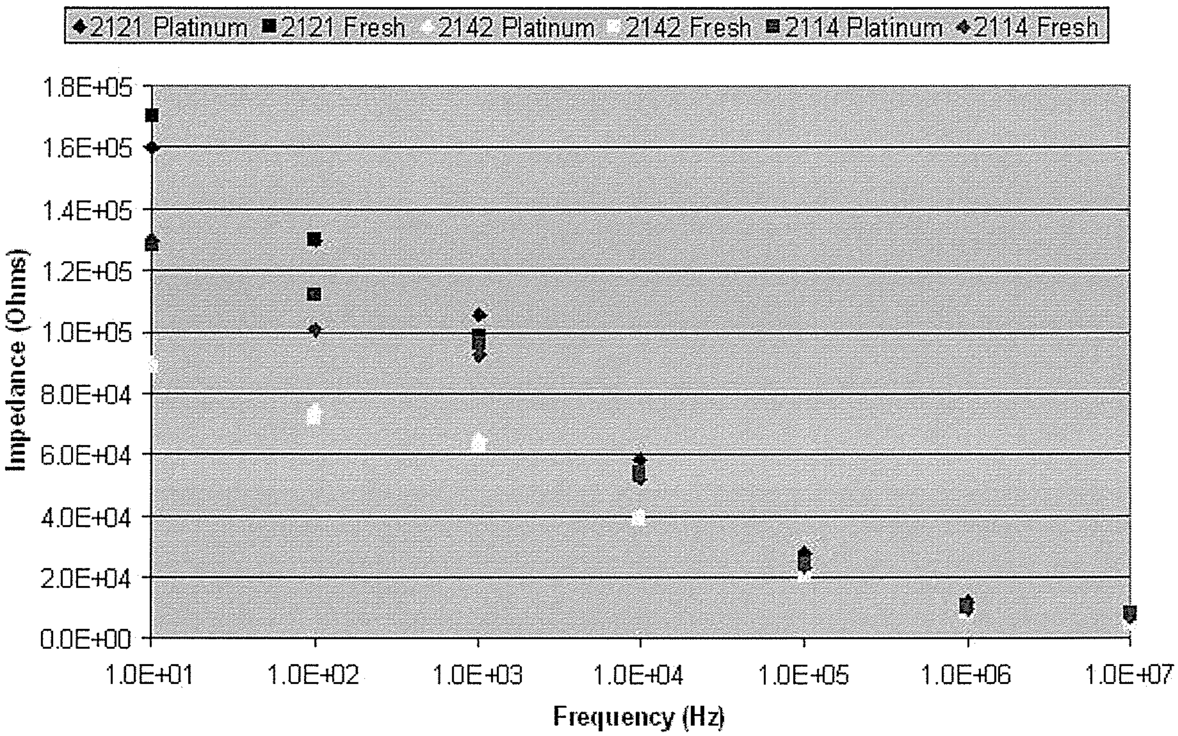

Figure 7: Live Plants: 7.2cm Spacing

The increased impedance of the platinum pins was also observed with dried out plants 2142 and 2114. This is because in the drying process, along with losing conductive fluids, the plant fibers also shrank away from the pins and good connections were not being made inside the plants. It was easy to observe this phenomenon during testing because the platinum pins would easily fall out of the Thlapsi stem. For the 2121 plant, it appears that while the plant was still alive, it was able to grow around the platinum pins and create a good connection between the plant and the pin. More testing in the future can determine if this is the case or not by allowing the plants to grow around pins for periods longer than 2 weeks.

Besides being interested in the differences between dead plants and living plants, properties regarding length and different frequencies are also of interest to the project. All three types of plants were tested to display the relations between impedance, frequency, and distance. These plants were all living and freshly made pin connections were used in the test. A plant of type 2121 will be used to display the relations between impedance versus frequency and impedance versus distance in Figures 9 and 10 respectively. The results from the other two plants closely approximate those found in the 2121 plant, and their results can be seen in Appendix A.

As with the sunflower and grapevines, it was found that impedance decreases in a logarithmic relation to the testing frequency. Figure 9 displays these measurements for 8 different spacings. The measurements at the different spacings all follow the expected trend of the greater the spacing the higher the impedance and the lower impedance for higher frequencies. Figure 10 displays the relationship between the spacing and the impedance in greater detail. It is expected that the impedance will linearly increase with the distance between the probes. Figure 10 clearly supports this theory.

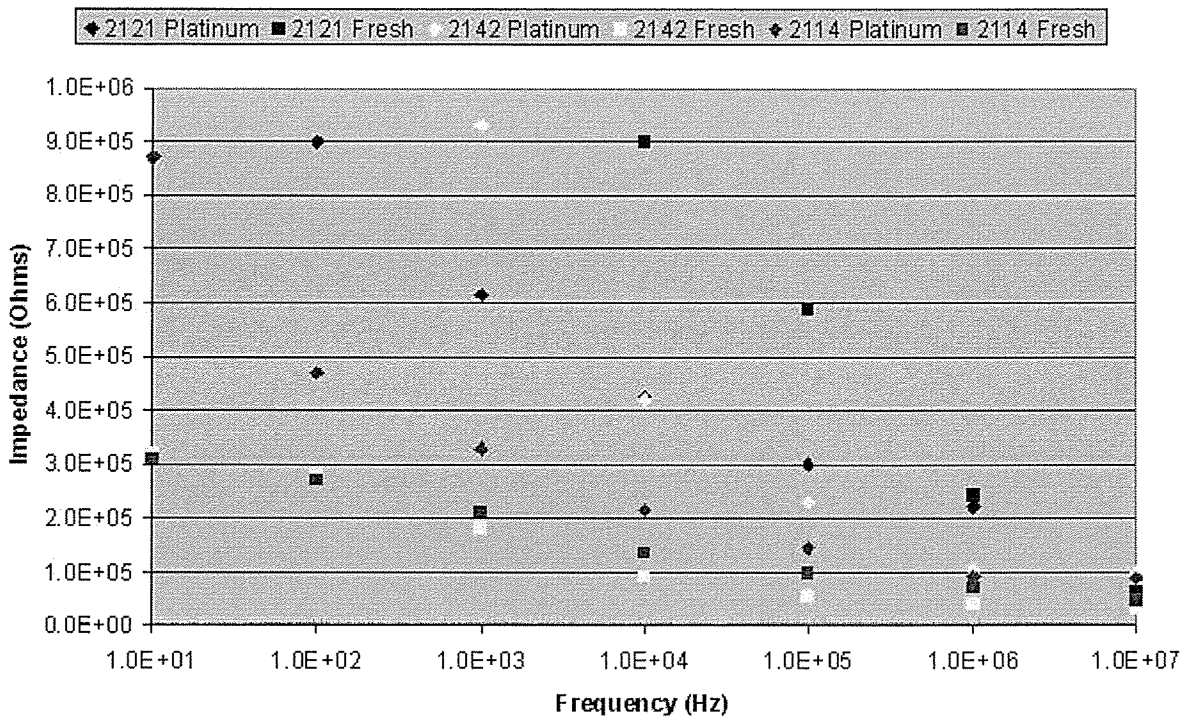

Figure 8: Dried Plants: 7.2cm Spacing

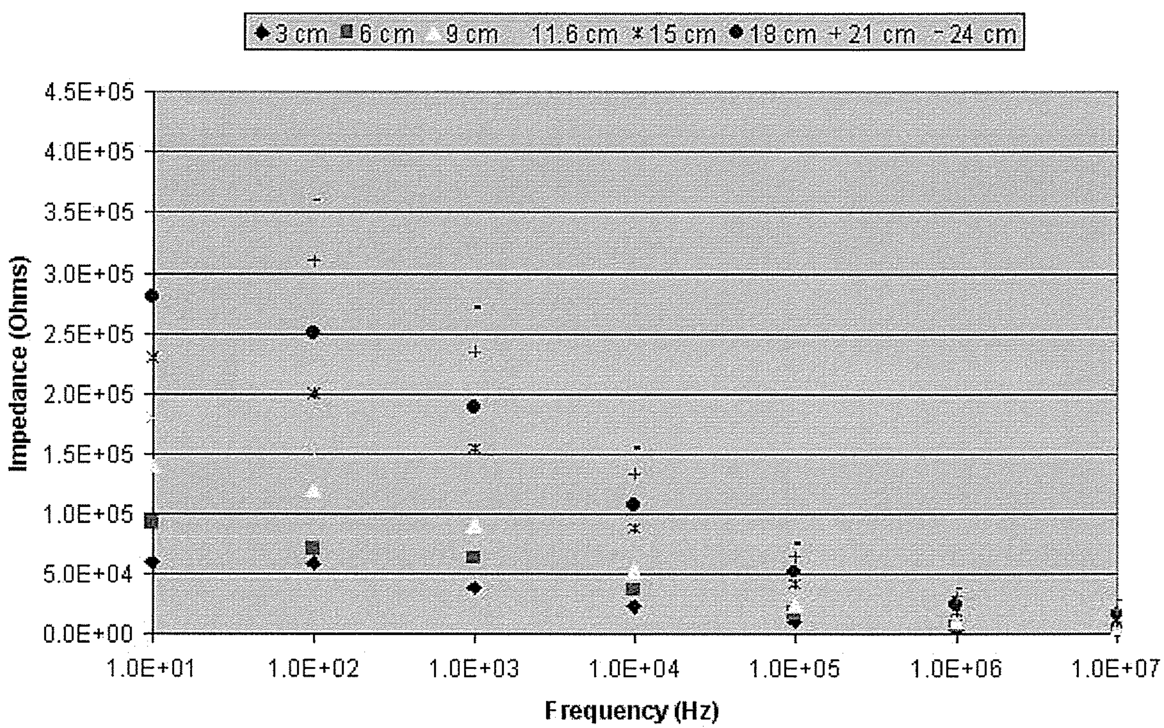

Figure 9: Plant 2121: Impedance versus Frequency for Various Lengths

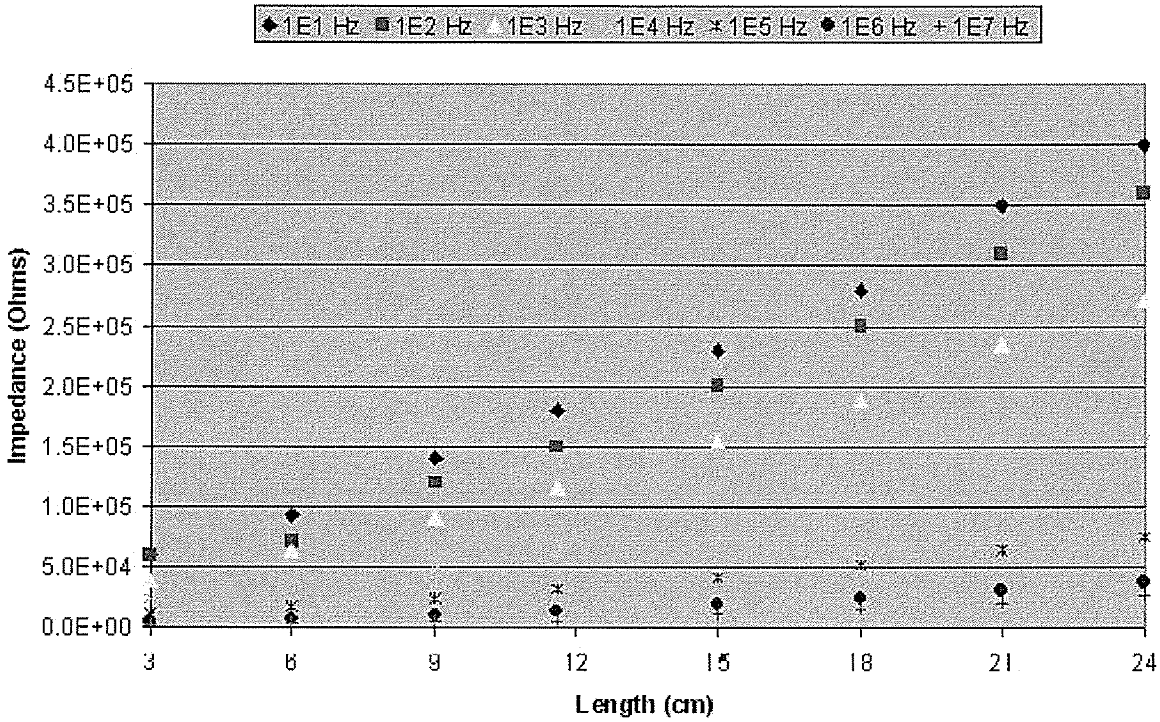

Figure 10: Plant 2121: Impedance versus Length for Various Frequencies

Summary

The Plantenna project is a unique research experiment in that it has never been attempted before. The research in this uncharted area had to start from the very beginning because there is no former knowledge base to draw upon. Questions about how to measure the impedance of a plant quickly brought on other questions about the best way to design the test and the equipment to use during testing. The Plantenna project is currently on its second iteration of improving the impedance measurements with the four-wire apparatus. However, it still remains to be determined what is an optimal way to connect to the plant for measurements. Attempts at placing pins in the plant weeks before testing to allow the plant to grow around and incorporate the probes into the plant structure were the first attempts at finding a better method of connecting to the plant. In the future, different sized and shaped probes will be used to see if there are any improvements as well as using some kind of conductance enhancing gel or solution to allow the probe to make better contact with the plant.

Impedances obtained from testing are still too large to indicate that the plants are as good as a manufactured antenna. The lowest impedances measured on the Thlapsi were approximately 2000 Ohms at a spacing of 3 cm. However, the results obtained from testing display several positive qualities. One is that these plants will act as a very crude antenna in that the plants will conduct signals of various frequencies down the length of the plant. Another is that the impedance of the plants behaves in an expected manner. These are good indicators that the Plantenna project can continue forward and create better testing procedures and better plants for testing so that one day plants might be used as antennas.

Appendix A

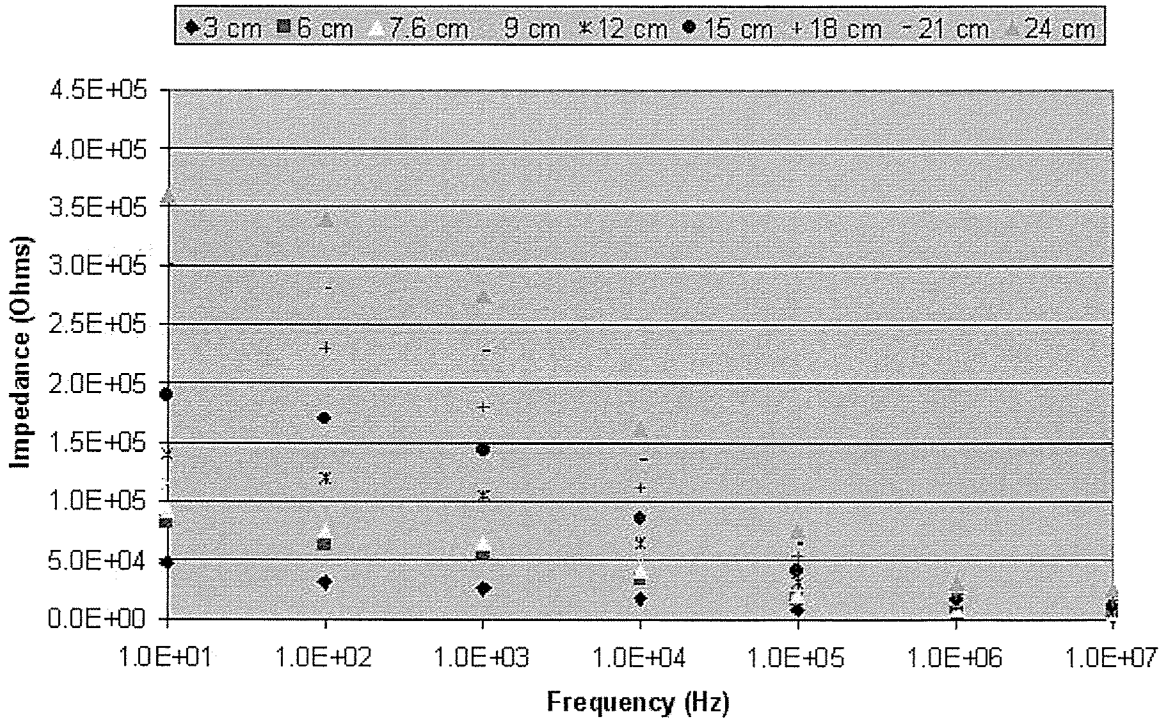

Figure A1: Plant 2142: Impedance versus Frequency for Various Lengths

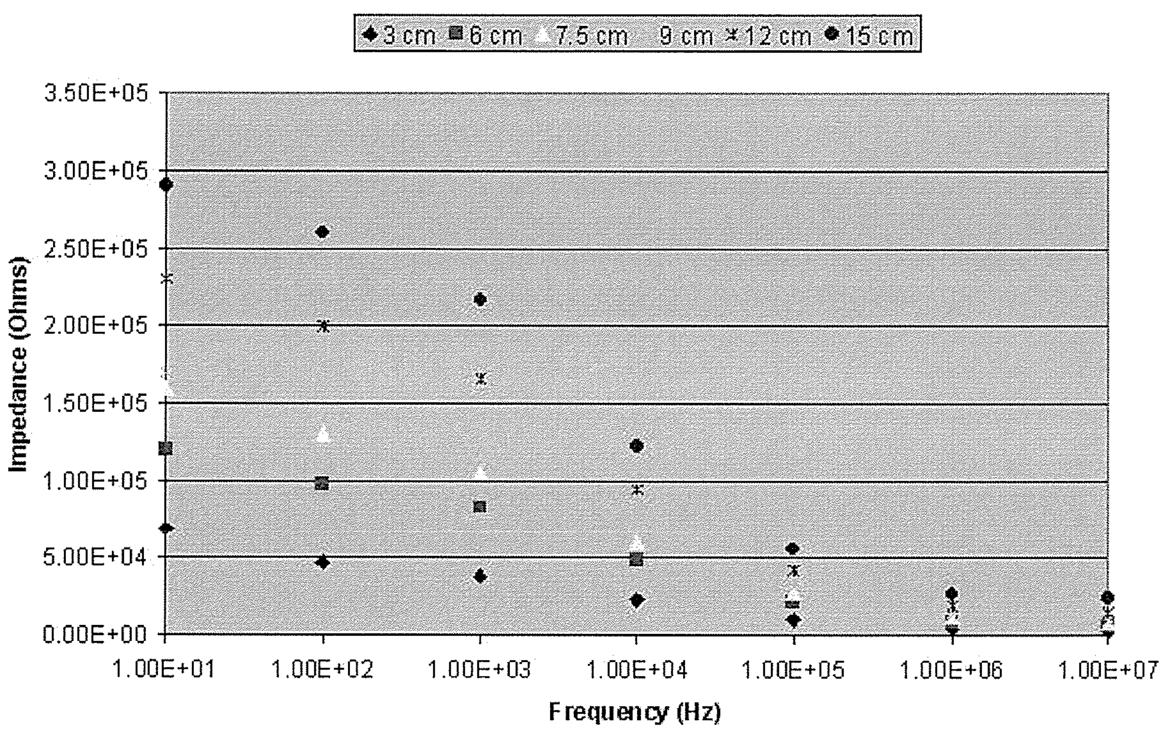

Figure A2: Plant 2114: Impedance versus Frequency for Various Lengths

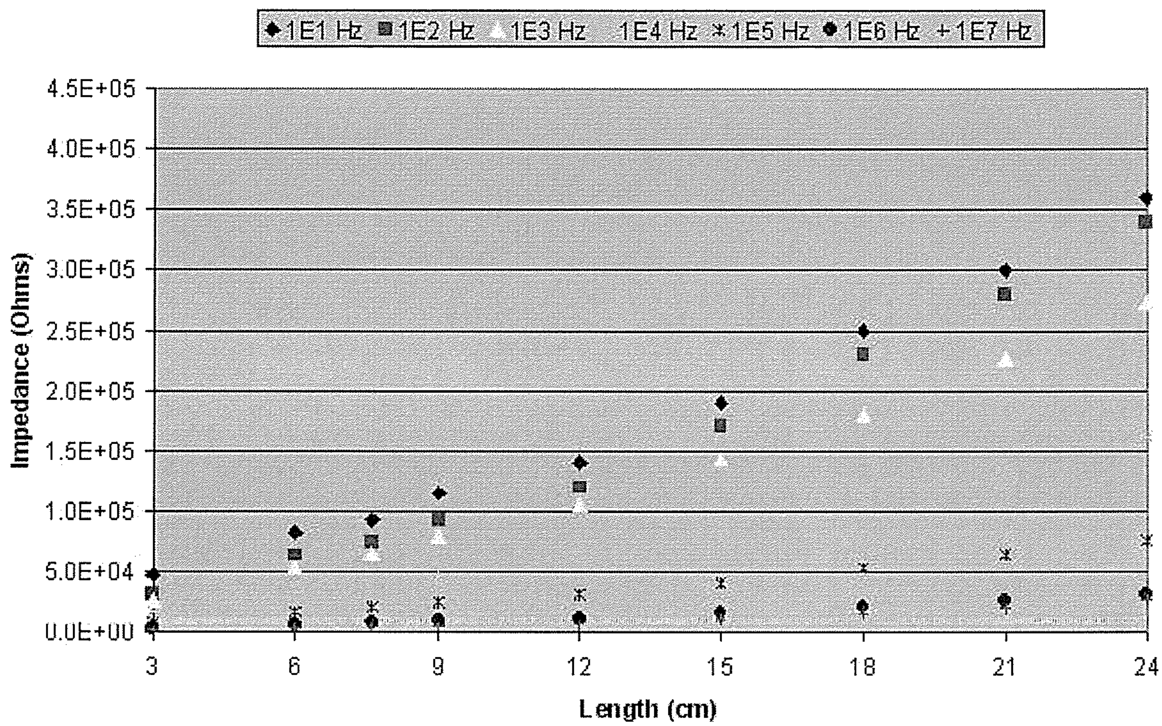

Figure A3: Plant 2142: Impedance versus Length for Various Frequencies

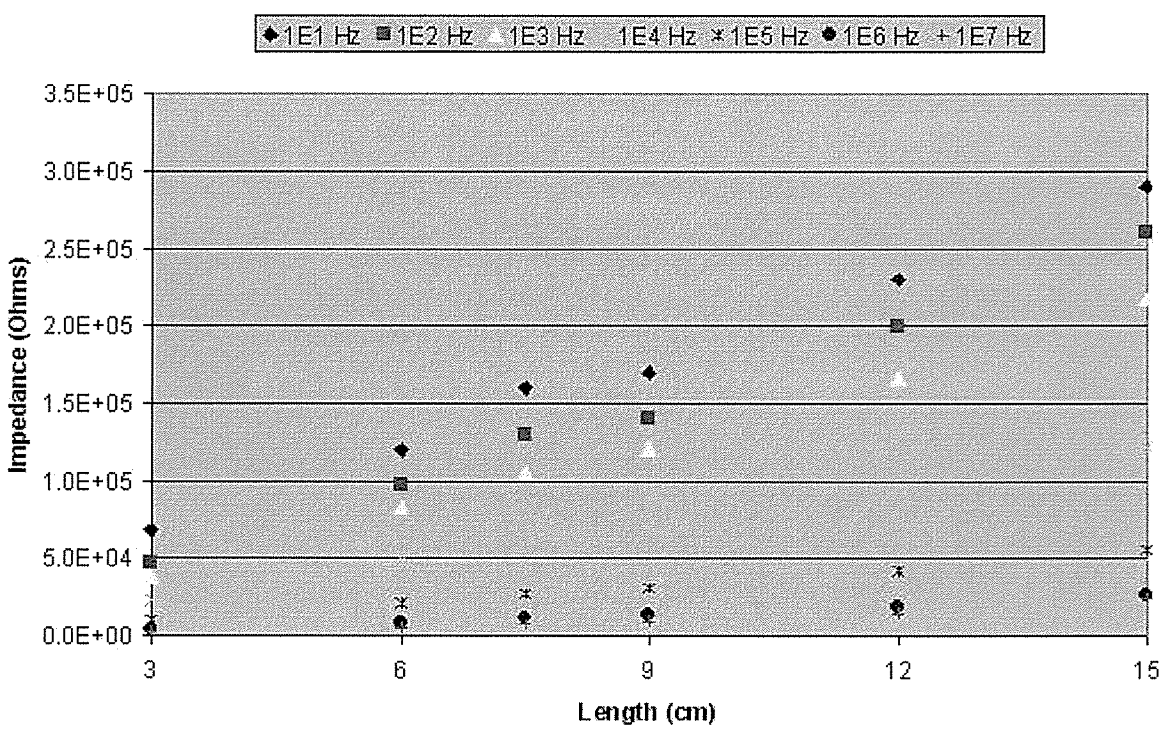

Figure A4: Plant 2114: Impedance versus Length for Various Frequencies